Late Ordovician Faunas from the Quandialla-Marsden District, South-central New South Wales

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Percival, I.G., Zhen, Y.Y. and Pickett, J.W. (2006). Late Ordovician faunas from the Quandialla-Marsden district, south-central New South Wales. *Proceedings of the Linnean Society of New South Wales* **127**, 235-255.

Two Late Ordovician faunas, one from shallow water limestones and the other from deep water spiculitic siltstones, are documented from the southern Macquarie Arc in south-central New South Wales. Limestone encountered in the subsurface during exploration drilling in the Barmedman Creek area (midway between Marsden and West Wyalong) yields Eastonian conodonts including *Aphelognathus* cf. *webbyi*, *Belodina compressa*, *Phragmodus undatus*, *Tasmanognathus* cf. *borealis* and *Yaoxianognathus*? *tunguskaensis*. Associated macrofauna includes the corals *Tetradium tenue*, *Bajgolia*? cf. *grandis*, *Propora bowanensis*, *Paleofavosites*?, *Cystihalysites*, *Halysites* and *Palaeophyllum*, stromatoporoids *Labechiella variabilis*, *Stratodictyon ozakii*, *Clathrodictyon* cf. *microundulatum* and *Ecclimadictyon*, and sponge *Cliefdenella* cf. *perdentata*. The Jingerangle Formation, exposed between Caragabal and Quandialla, may be as young as Bolindian 2 on the basis of some poorly preserved graptolites. Associated nektic nautiloids and sponges (*Hindia*) represent components of Benthic Assemblage 4-5, suggesting a deep water environment. The limestones at Barmedman Creek, and the spiculitic clastic rocks of the Jingerangle Formation, are associated (although exact relationships are unclear) with two separate volcanic complexes in the Macquarie Arc. Late Ordovician successions exposed further north in the area west of Parkes and Forbes, where early to late Eastonian limestones are overlain by early Bolindian deep water sediments, provide the closest regional analogues to the fossiliferous strata documented in the paper.

Manuscript received 13 September 2005, accepted for publication 7 December 2005

KEYWORDS: biostratigraphy, conodonts, corals, Macquarie Arc, nautiloids, Ordovician, palaeoecology, sponges, stromatoporoids

INTRODUCTION

Late Ordovician shelly fossils documented in this paper are the most southerly known from the Junee-Narromine Volcanic Belt of the Ordovician Macquarie Arc in central and southern New South Wales (Glen et al. 1998). The study area, between Marsden and Quandialla, is not far from the Cowal Mine, presently under development near Lake Cowal (Fig. 1). The impetus of mineralisation potential in the area led to a recent drilling program by Newcrest Exploration at the company's Marsden prospect at Barmedman Creek, 25 km northeast of West Wyalong, disclosing the presence of a previously unsuspected limestone that has proven to be of Eastonian age. A moderately diverse Late Ordovician fauna has long been known from the Jingerangle Formation in the Quandialla district, approximately midway between West Wyalong and Grenfell (Fig. 1), but has remained undescribed until now. This fauna is somewhat younger than that obtained from the limestone at Barmedman Creek. Together, these Late Ordovician fossils provide important palaeontological constraints in an area of poor or hidden outcrop, and enable correlation with better-known and well-exposed successions further north along this belt in the region west of Parkes.

STRATIGRAPHIC SETTING AND BIOSTRATIGRAPHIC DETERMINATIONS

Unnamed limestone, Marsden prospect at Barmedman Creek

Newcrest Exploration encountered limestone in three cored drill holes at their Marsden prospect in the Barmedman Creek area, located in the vicinity of the Mid Western Highway 22 km west of Grenfell (Fig. 1). Cores from two of these holes, DDMN 042 and ACDMN 043, were extensively sampled for conodonts and macrofossils. Logs of these cored intersections (kindly provided by Irvine Hay of Newcrest) are shown in Figure 2. The remaining hole, ACDMN 045, was spot-sampled for macro- and microfossils over the depth interval 273-276.5 m. This interval yielded sparse conodonts (sample C2077) and one coral from 276 m. Total thickness of the limestone cannot be accurately determined due to the prevalence of faulting in the other two cores. In ACDMN 043, a 15 m-thick zone of fault gouge cuts through the middle of a limestone interval approximately 42 m in thickness. This faulted zone coincides with a series of intermixed and out-of-sequence biostratigraphic determinations (Fig. 2). The 33 m of apparently continuous limestone intersected in DDMN 042 is faulted at its top.

Composition and age significance of the conodont fauna

Limestone intersected in the Newcrest drilling program yielded 96 identifiable conodont specimens recovered from 12 samples. Sample weights varied from 900 g to 3.9 kg (average 1.7 kg), with the larger samples being obtained from intersections of several metres. Limestone samples were dissolved in dilute acetic acid and separated using sodium polytungstate. The conodonts, illustrated in Figs 3-4, are referrable to nine species (Table 1) which indicate a Late Ordovician (Eastonian) age.

Species of biostratigraphic significance include *Belodina compressa*, *Plectodina tenuis*? and *Phragmodus undatus*. All three are zonal index species of the North American Mid-continent biostratigraphic scheme, though it has been recognised that differences in local ranges and relative abundances present difficulties in precisely correlating with the North American zonation (Zhen and Webby 1995, Zhen et al. 1999). *Belodina compressa* first appears in NSW in the late Gisbornian upper part of the Wahringa Limestone Member (Zhen et al. 2004) and was replaced by *B. confluens* in limestones of early Eastonian age throughout the Macquarie Arc. Though mostly confined to slightly younger (Ea2-3) horizons where previously recorded in these limestones, *Phragmodus undatus* also is rarely present within the lower Billabong Creek Limestone (Gisbornian age) in the vicinity of Gunningbland, northward along the Junee-Narromine Volcanic Belt (Pickett and Percival 2001, appendix 1). *Plectodina tenuis*?, only tentatively identified in the Marsden core from a couple of elements, is elsewhere in NSW restricted to early Eastonian (Ea1-2) strata. Co-occurrence of *P. undatus* with *B. compressa* and *P. tenuis*? in sample C2077 (273-276 m in borehole ACDMN 045) therefore most likely implies a basal Eastonian age for this level.

The presence of *Yaoxianognathus*? *tunguskaensis*, *Aphelognathus* cf. *webbyi* and *Tasmanognathus* cf. *borealis* in the assemblage also supports an Eastonian age assignment. *Yaoxianognathus*? *tunguskaensis* is widely distributed in limestones of this age throughout the Macquarie Arc. *Aphelognathus webbyi* is common in the early Eastonian Fossil Hill Limestone of the Cliefden Caves Limestone Group (Savage 1990, Zhen and Webby 1995). *Tasmanognathus borealis* was recorded from the Yiaoxian Formation (mid-early Eastonian age equivalent) of North China, where it is associated with *Phragmodus undatus* and *Taoqupognathus blandus* (An and Zheng 1990).

Apparently absent from the fauna are any examples of *Taoqupognathus*, species of which are biostratigraphically significant in Eastonian limestones in central NSW and China (Zhen et al. 1999, Zhen 2001). Another characteristic feature of the Barmedman Creek limestone is the occurrence of *Rhipidognathus*, which has not previously been noted from NSW.

Coral and stromatoporoid assemblages

All three of the Newcrest boreholes at the Marsden prospect yielded corals, and one also included stromatoporoids. These are illustrated in Figs 5-9, and their occurrences are detailed in Table 2.

Three samples from borehole DDMN 042 all yielded a single species of coral, *Tetradium tenue*, which is known only from the *Hillophyllum-Tetradium-Rosenella* Assemblage Zone (Pickett and Percival 2001) of Ea1 age. The material from borehole ACDMN 045 is poorly preserved, with only a provisional determination of *Tetradium*? sp., implying a generalised early Eastonian age, which is in accord with the conodont-based age from sample C2077 (273-276.5 m in ACDMN 045) previously mentioned.

The most abundant material is from borehole ACDMN 043, which, in addition to forms already known from NSW, also includes a number of unusual occurrences. *Stratodictyon ozakii* was previously recorded only from the *Hillophyllum-Tetradium-Rosenella* Assemblage Zone, but is here associated with forms characteristic of younger levels.

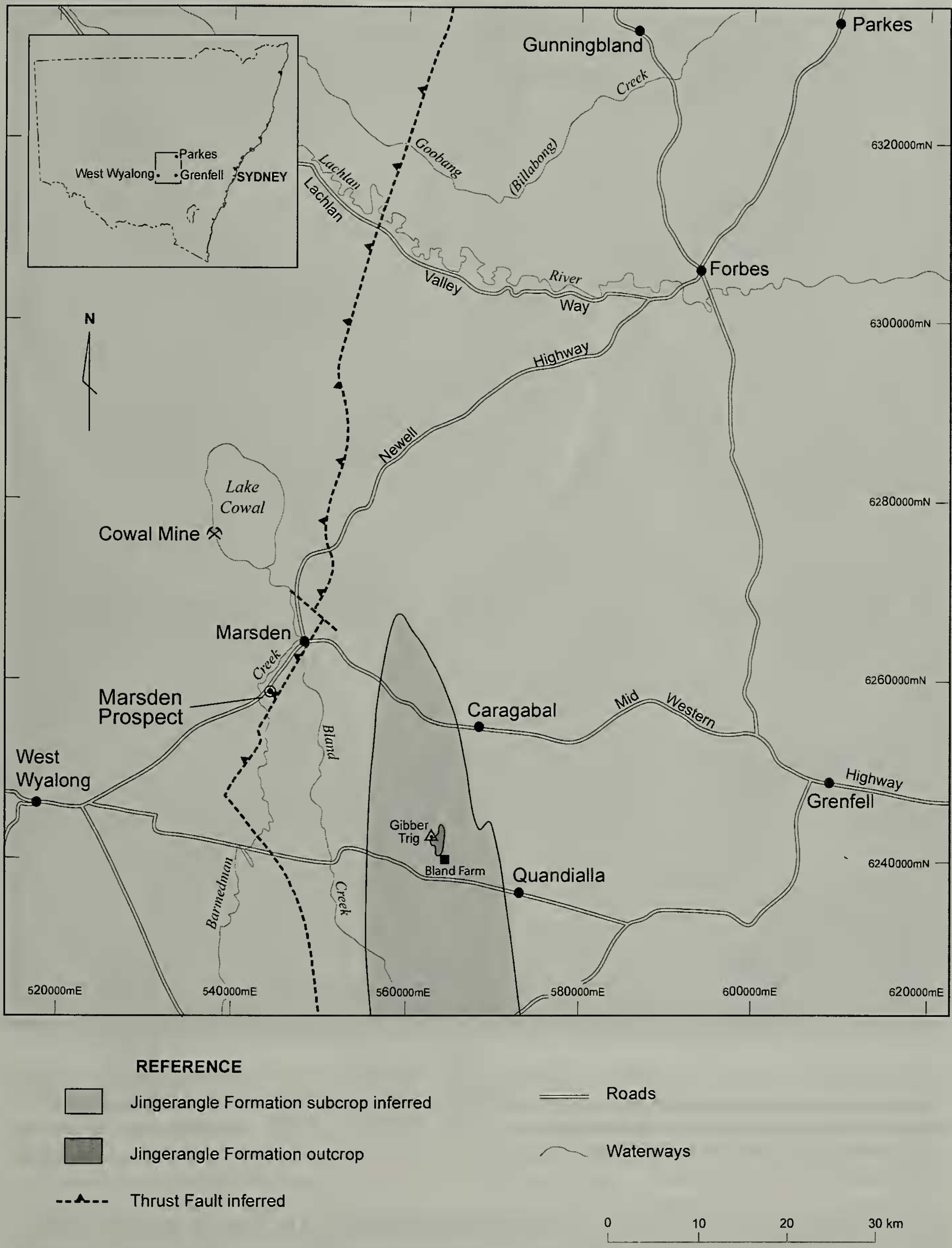


Figure 1. Locality map of south-central New South Wales showing places mentioned in the text. Simplified geological data, including location of Marsden prospect drill sites, the regional thrust fault, and outcrop and subsurface extent of the Jingerangle Formation (incorporating the Currumburrama volcanics) are derived from the Forbes 1:250 000 Geological Map (second edition).

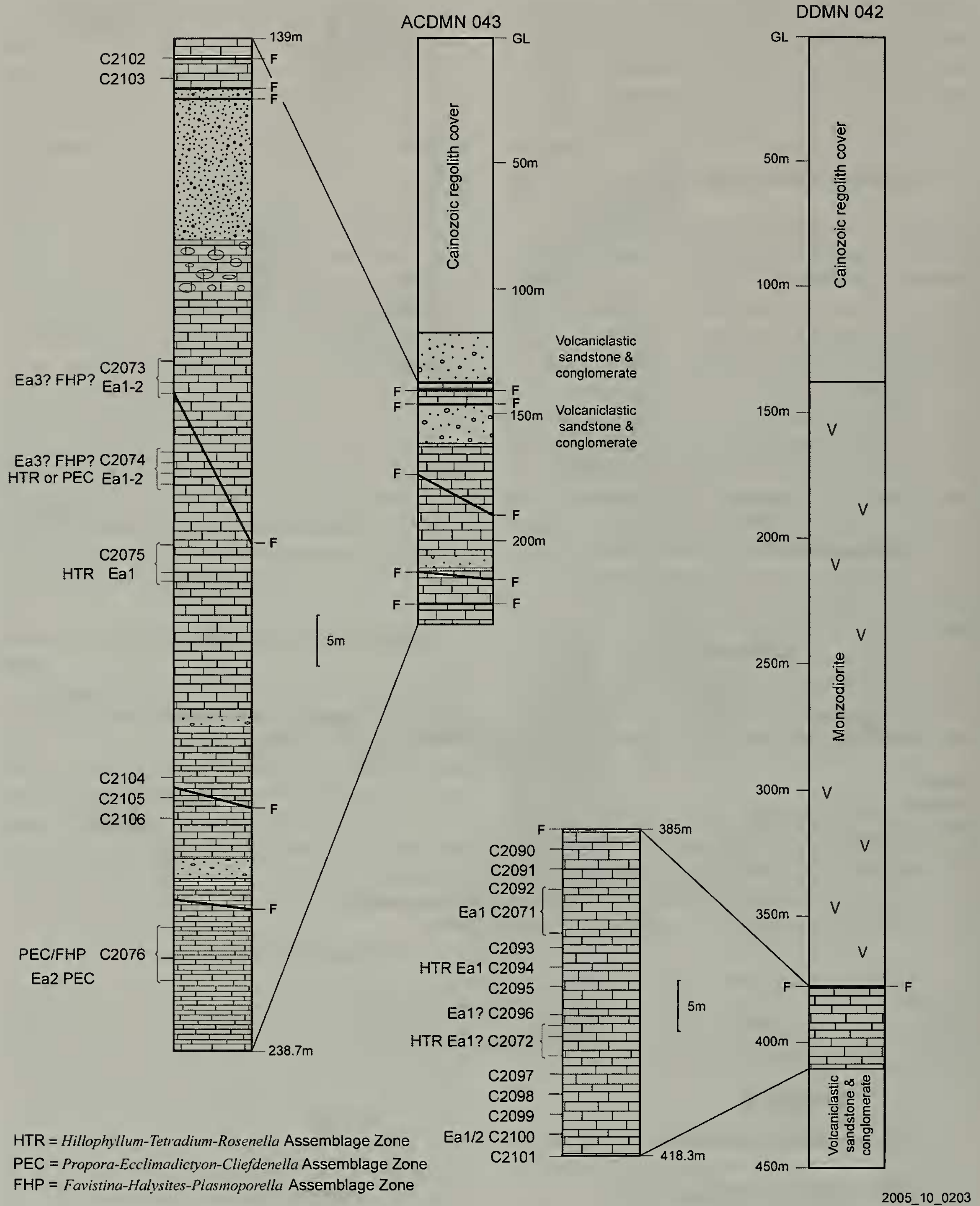


Figure 2. Diagrammatic representation of major lithologies intersected in Newcrest boreholes DDMN 042 and ACDMN 043 in the Marsden prospect, with enlargement of limestone-dominated intervals to show sampled horizons and faunas recovered. GL = ground level; F = fault; Ea = Eastonian Stage, with subdivisions Ea1 (oldest), Ea2, Ea3 (youngest). See text for discussion of age relationships of macrofossil Assemblage Zones (defined in Pickett and Percival 2001) and conodonts (C samples).

Figure 3. SEM photographs of conodonts from Eastonian limestone in core, Marsden prospect at Barmedman Creek; scale bars 100 µm. A-D, *Belodina compressa* (Branson and Mehl, 1933). A, B, grandiform elements, from C2071, A, MMMC4122, outer lateral view; B, MMMC4123, inner lateral view; C, D compressiform elements, from C2072, inner lateral views, C, MMMC4124, D, MMMC4125. E-H, *Panderodus gracilis* (Branson and Mehl, 1933). E, F, tortiform element, MMMC4126, from C2071, E, outer lateral view, F, inner lateral view; G, falciform element, MMMC4127, from C2095, outer lateral view; H, falciform element, MMMC4128, from C2096, outer lateral view. I, J, *Panderodus* sp. I, "b" element, MMMC4129, from C2072, outer lateral view; J, "a" element, MMMC4130, from C2073, outer lateral view. K, L, *Plectodina tenuis*? (Branson and Mehl, 1933). K, S element, MMMC4133, from C2077, posterior view; L, Pb element, MMMC4132, from C2071, inner lateral view. M, *Tasmanognathus* sp. cf. *T. borealis* An, in An et al., 1985. Pa element, MMMC4131, from C2075, inner lateral view.

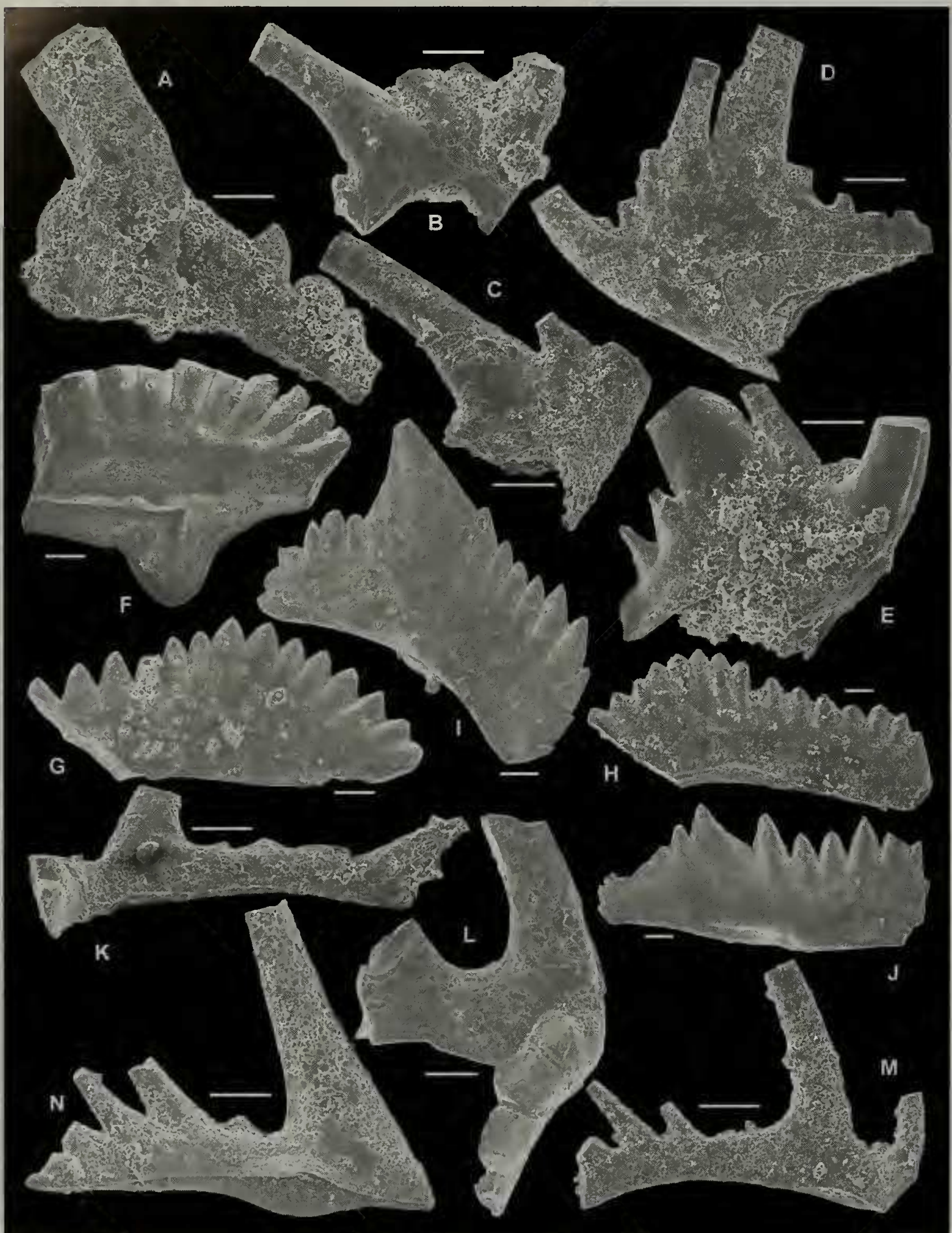


Figure 4. SEM photographs of conodonts from Eastonian limestone in core, Marsden prospect at Barmedman Creek; scale bars 100 µm. A-E, *Phragmodus undatus* Branson and Mehl, 1933. A, Pa element, MMMC4134, from C2100, anterior view; B, Sc element, MMMC4135, from C2077, inner lateral view; C, Sc element, MMMC4136, from C2077, outer lateral view; D, Sb element, MMMC4137, from C2094, outer lateral view; E, Sb element, MMMC4138, from C2094, inner lateral view. F-I, *Rhipidognathus* sp. F, Sb element, MMMC4139, from C2075, posterior view; G, Pa element, MMMC4140, from C2094, inner lateral view; H, Pa element, MMMC4141, from C2072, inner lateral view; I, Pb element, MMMC4142, from C2073, inner lateral view. J, *Aphelognathus* sp. cf. *A. webbyi* Savage, 1990. Pa element, MMMC4143, from C2075, outer lateral view. K-N, *Yaoxianognathus*? *tunguskaensis* (Moskalenko, 1973). K, Sd? Element, MMMC4144, from C2074, inner lateral view; L, Sb element, MMMC4145, from C2075, inner lateral view; M, Sc element, MMMC4146, from C2073, inner lateral view; N, M element, MMMC4147, from C2074, posterior view.

Table 1. Distribution of conodonts in Newcrest boreholes, Marsden prospect, Barmedman Creek; C2077 from ACDMN 045, 273-276.5 m depth; for details of other samples see Appendix.

SAMPLES / CONODONT TAXA	C2071	C2072	C2073	C2074	C2075	C2077	C2093	C2094	C2095	C2096	C2097	C2100	Total
Aphelognathus cf. *webbyi*			1	1	7								9
Belodina compressa	3	2			3	2				2			12
Panderodus gracilis	5	6	1	8	8	5			7	2	1	1	44
Panderodus sp.		1	1	5	1								8
Phragmodus undatus						2		2				1	5
Plectodina tenuis?	1					1							2
Rhipidognathus sp.		1	1	1	1			1					5
Tasmanognathus cf. *borealis*					1					1			2
Yaoxianognathus tunguskaensis			2	3	3		1						9
Total	9	10	6	18	24	10	1	3	7	5	1	2	96

Labechiella variabilis, *Bajgolia*? cf. *grandis*, the heliolitids and *Ecclimadictyon* are typical of the *Propora-Ecclimadictyon-Cliefdenella* Assemblage Zone, of Ea2 age, while *Paleofavosites* and halysitids are only known from the next-youngest (Ea3-4) *Favistina-Halysites-Plasmoporella* Assemblage Zone (Pickett and Percival 2001). *Cystihalysites* has so far not been reported from strata younger than Early Silurian, so its occurrence here, apart from being the first report of the genus in Australia, is outside its known range.

Synthesis: age of the Barmedman Creek limestone

Regional biostratigraphic zonation of Upper Ordovician limestones within the Macquarie Arc of central NSW is well-established, based on integrated macrofaunal and microfaunal assemblages. Diagnostic taxa from three of the coral-stromatoporoid faunas first recognised by Webby (1969), updated by Webby et al. (1997) and more recently formalised by Pickett and Percival (2001), are identified in limestone from two of the cored holes. Though the conodont faunas recovered lack *Taoqupognathus*, a key component of the local zonation (Zhen 2001), sufficient associated species are present to confirm the ages of most individual samples.

When plotted against the log of the Newcrest drill hole DDMN 042 (Fig. 2), occurrence of a coral species restricted to the *Hillophyllum-Tetradium-Rosenella* Assemblage Zone (Pickett and Percival 2001) is consistent with presence of early Eastonian (Ea1) age conodonts. Indeed, the identification of *Belodina compressa* in three samples from this core, which are closely associated with the levels that produced the coral *Tetradium tenue*, implies a basal Eastonian age.

The sequence of macrofaunal assemblages and conodonts in ACDMN 043 is more problematic, and only makes sense when details from the lithology log are integrated with the palaeontological sampling (Fig. 2). Samples from the deepest limestone intersected (229 and 232 m) are consistent with an Ea2 age, based on presence of a diverse suite of corals and stromatoporoids of the *Propora-Ecclimadictyon-Cliefdenella* Assemblage Zone. Above a barren interval, samples from 189-193 m yield both conodonts and stromatoporoids indicative of an earlier, Ea1, age. This succession is at variance with what would be expected, and may imply the presence either of a fault (unrecognised in the core) or an overturned sequence. Within the interval 174-182 m, ages are mixed in a zone identified on the log as extensively faulted. The lowermost sample from this faulted zone contains sponges (including stromatoporoids) consistent with an early Eastonian age (Ea1-2), that is overlain by limestone with sponges and corals (including halysitids) suggesting a younger, Ea3, age. However, conodonts from a sample extending over the interval 179.5-183.9 m that includes the aforementioned macrofossil assemblages, are definitely of Ea1-2 age — confirming structural interleaving of fault slices. Samples from shallower depths exhibit a similar intermixing of ages, with macrofossils from 173 and 174 m characteristic of the *Favistina-Halysites-Plasmoporella* Assemblage Zone (Ea3) associated with Ea1-2 conodonts from sample C2073. The two highest samples unfortunately yield no biostratigraphically useful information.

The Marsden prospect is located on the western (hangingwall) block of a major regional thrust fault (Fig. 1). Although the faulting has disrupted the normal biostratigraphic succession in the drill core, it has had the fortunate effect of demonstrating — even in a relatively short intersection of limestone — that the limestone at Barmedman Creek commenced deposition in basal Eastonian time and continued

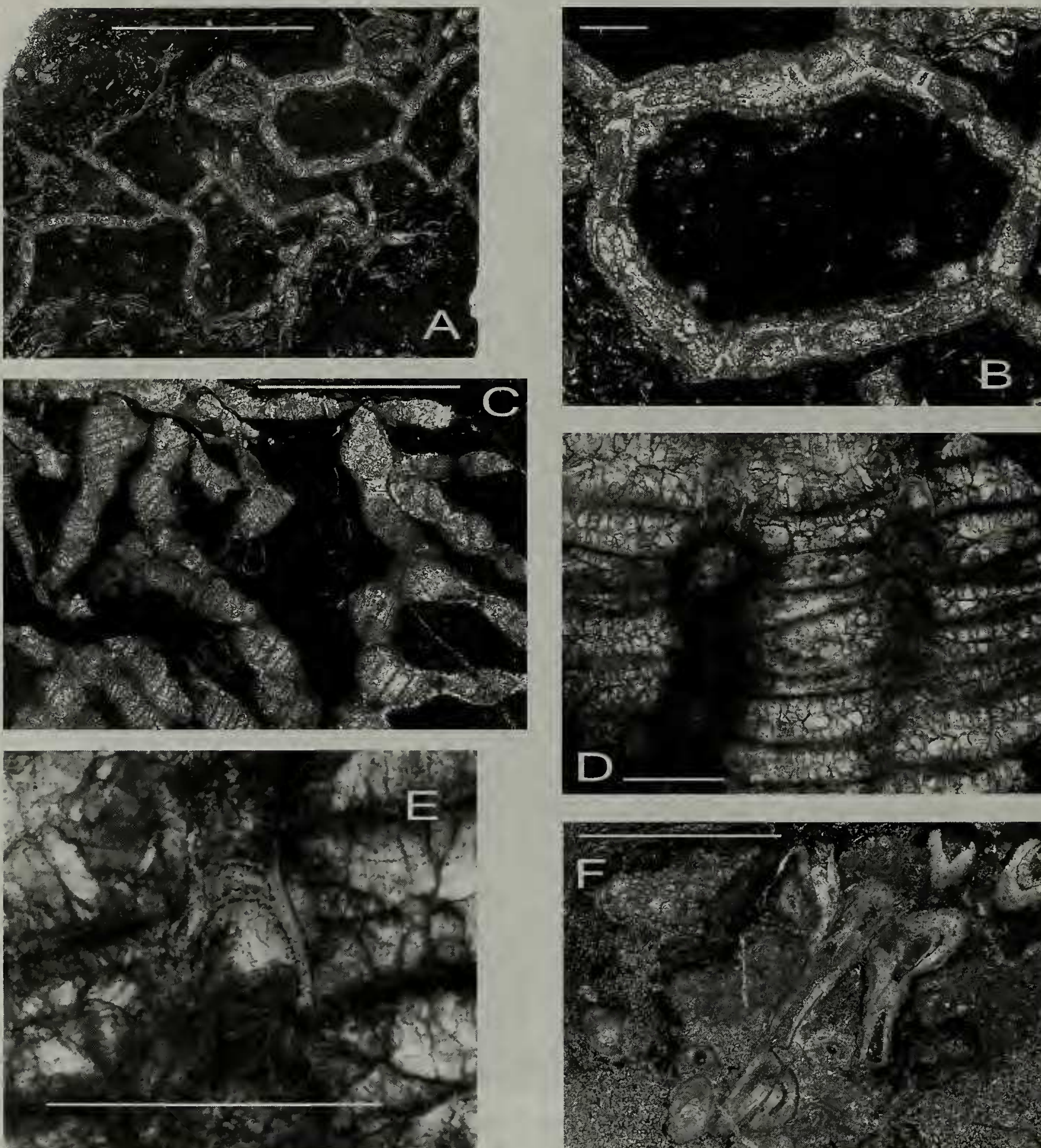


Figure 5. Tabulate corals from Eastonian limestone in core, Marsden prospect at Barmedman Creek. Scale bar shown in photos (A), (C) and (F) represents 10 mm. Scale bar in (B), (D) and (E) represents 1 mm. A, B, *Halysites* sp. from 173 m in ACDMN 043; A, transverse section; B, enlargement to show macro- and microcorallites. C, D, E, *Cystihalysites* sp. from 179-180 m in ACDMN 043; C, oblique transverse and longitudinal section; D, enlargement of the lower left corner of B, showing cystose coenenchymal tubules; E, detail of upper right corner of D, clearly displaying cyst. F, *Bajgolia*? cf. *grandis* Webby, 1977, oblique longitudinal section from 229 m in ACDMN 043.

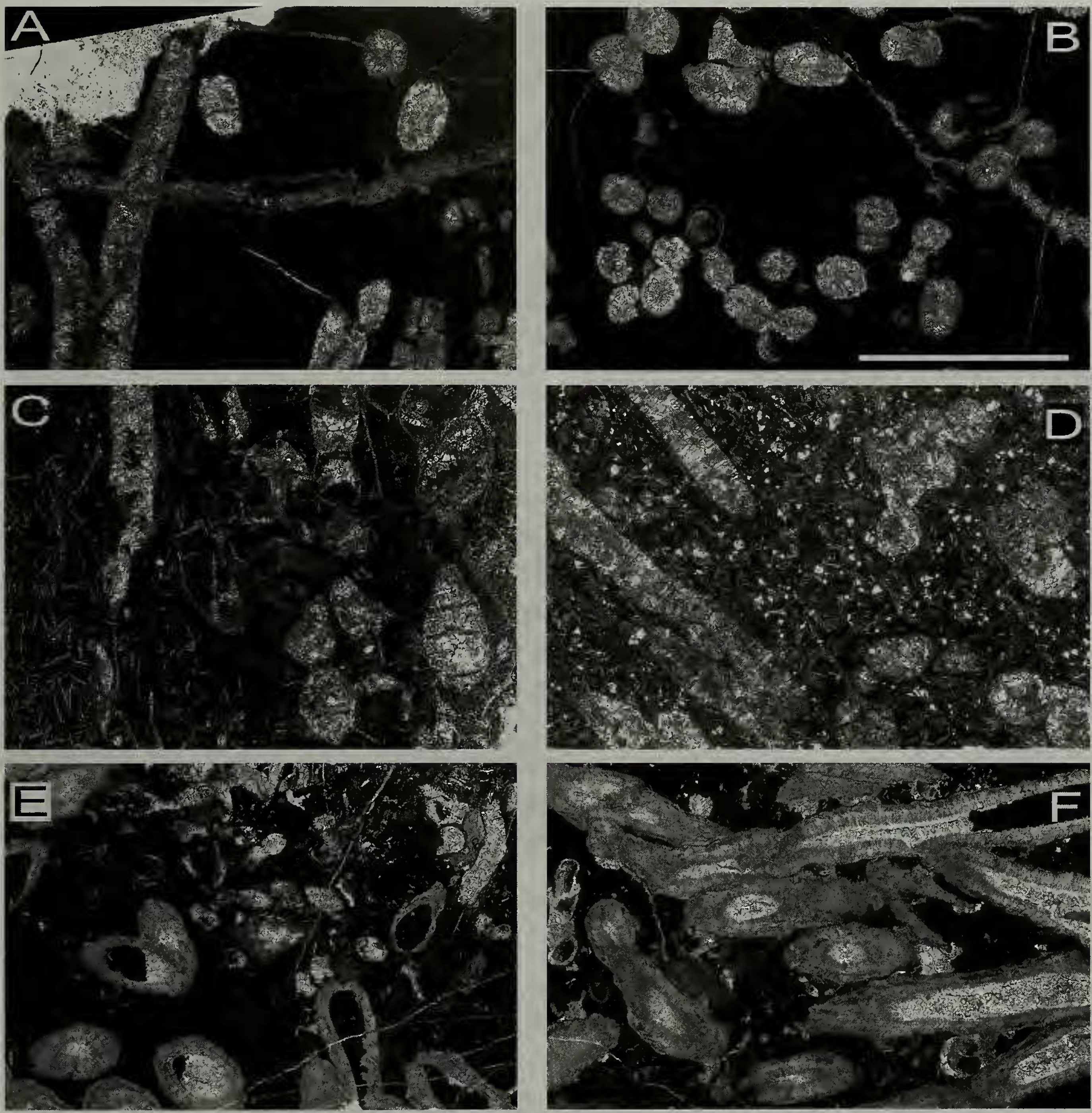


Figure 6. Corals from Eastonian limestone in core, Marsden propect at Barmedman Creek. Scale bar shown in photo (B) represents 10 mm and applies also to photos (A) and (C-F). A, B, *Tetradium tenue* Webby and Semenuik, 1971, longitudinal and transverse sections, from 399 m in DDMN 042. C, D, *Tetradium*? sp., oblique transverse section from 406 m in DDMN 042, and longitudinal section from 276 m in ACDMN 045. E, F, *Bajgolia*? cf. *grandis* Webby, 1977, transverse and oblique longitudinal sections from 232 m in ACDMN 043.

into the late Eastonian (Ea3). This age determination is significant in correlating the succession with limestones of Late Ordovician age elsewhere in the Macquarie Arc.

Jingerangle Formation

In the southernmost area of the Forbes 1:250 000 map sheet, south of the Mid Western Highway between Grenfell and West Wyalong, Ordovician formations are mostly hidden beneath alluvial cover of Cainozoic age. Very few outcrops stand above the plain, and fossiliferous strata are almost absent. The sole exception is the Jingerangle Formation which is best exposed in two road aggregate quarries in the vicinity of Gibber Trig (GR 560200mE 6244600mN, Marsden (8430 II and III) 1:50 000 sheet). This low hill is located immediately south of the Jingerangle State Forest, which is itself situated south of the

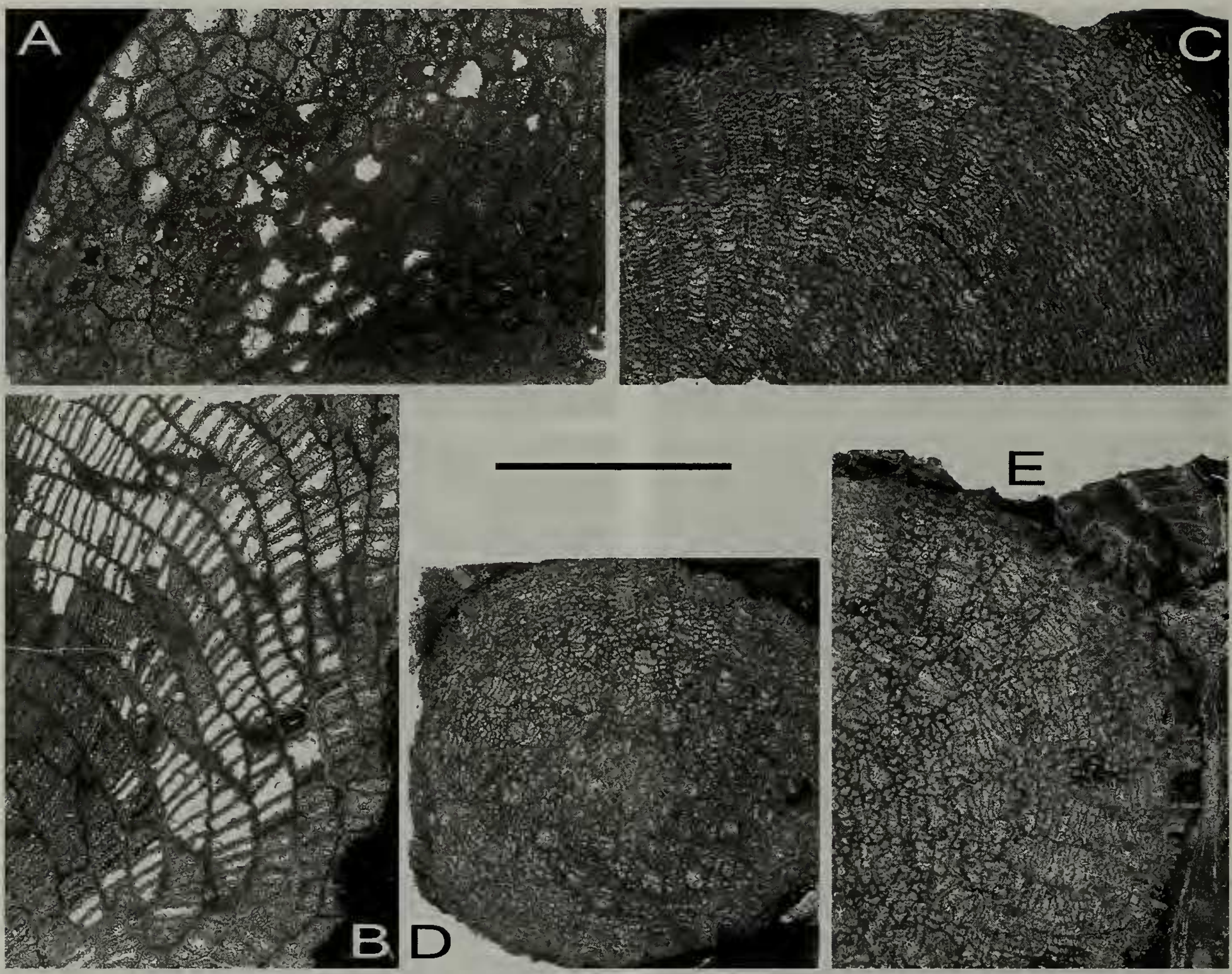


Figure 7. Tabulate and rugosan corals from Eastonian limestone in core, Marsden propect at Barmedman Creek. Scale bar represents 10 mm. A, B, *Paleofavosites*? sp., transverse and longitudinal sections, from 174 m in ACDMN 043. C, D, E, *Propora bowanensis* Hill, 1957, longitudinal, transverse and oblique sections from 229 m in ACDMN 043; note also transverse section through partial corallite of *Palaeophyllum* sp. in upper right corner of photo (E).

Mid Western Highway between Grenfell and West Wyalong about 37 km east of the latter town (Fig. 1). Further locality details are given by Lyons and Wallace (1999). Warren et al. (1995) named the unit and provided its formal description [despite their assertion that Bowman (1976) first described the Jingerangle Formation, no such name or distinguishing description appears either on the Forbes 1:250 000 metallogenic map or in the accompanying explanatory notes]. An up-to-date description of the Jingerangle Formation appears in the Explanatory Notes to the Forbes 1:250 000 Geological Sheet, 2nd edition (Percival and Lyons 2000).

The Jingerangle Formation is significant in containing the youngest, most diverse, Late Ordovician shelly macrofauna in central NSW, near the southernmost extent of outcrop of sediments associated with the Junee-Narromine Volcanic Belt. In this belt, only the lower section of the Cotton Formation (Sherwin 1973, Sherwin et al. 1987), on trend to the northeast just west of Forbes, appears to be of broadly comparable (Bolindian) age.

Lithologies in the lower Jingerangle Formation, exposed in the working road base quarry, mostly consist of a succession of thinly bedded siltstones and mudstones, the latter generally weathered into multicoloured clays (pink and white) and orange-brown ochres. The siltstones are more resistant as they are largely composed of sponge spicules, which provide a tightly interlocking meshwork of silica. Fresh recently exposed material is relatively dense and mostly dark grey in colour, but natural outcrops are weathered to a lighter biscuit-like texture, of grey-white appearance. The other major sediment type in

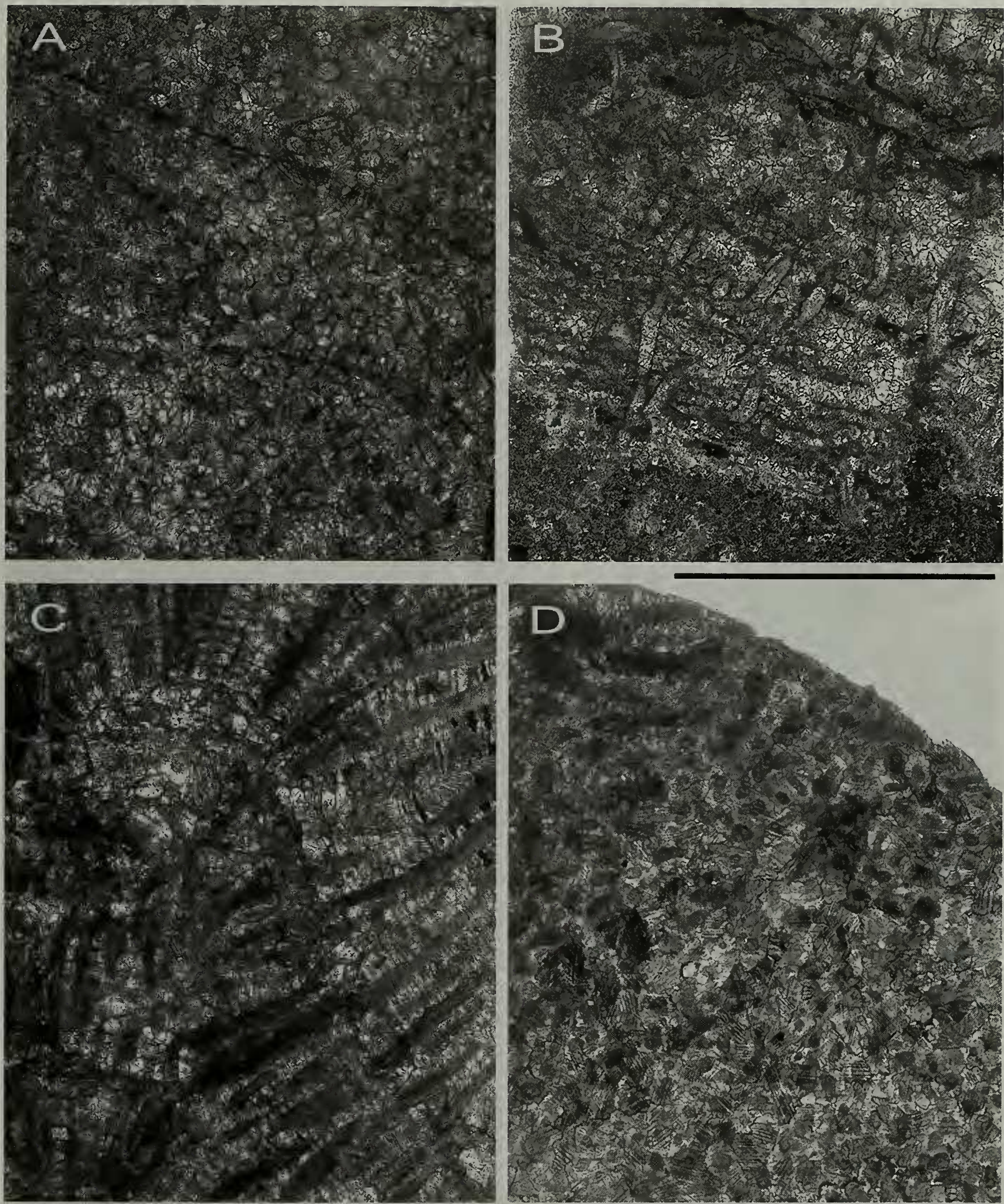


Figure 8. Sponges, including stromatoporoids, from Eastonian limestone in core, Marsden prospect at Barmedman Creek. Scale bar represents 10 mm. A, B, *Cliefdenella* cf. *perdentata* Webby and Morris, 1976, transverse and longitudinal sections, from 181 m in ACDMN 043. C, D, *Labechiella variabilis* (Yabe and Sugiyama, 1930), longitudinal and transverse sections from 192 m in ACDMN 043.

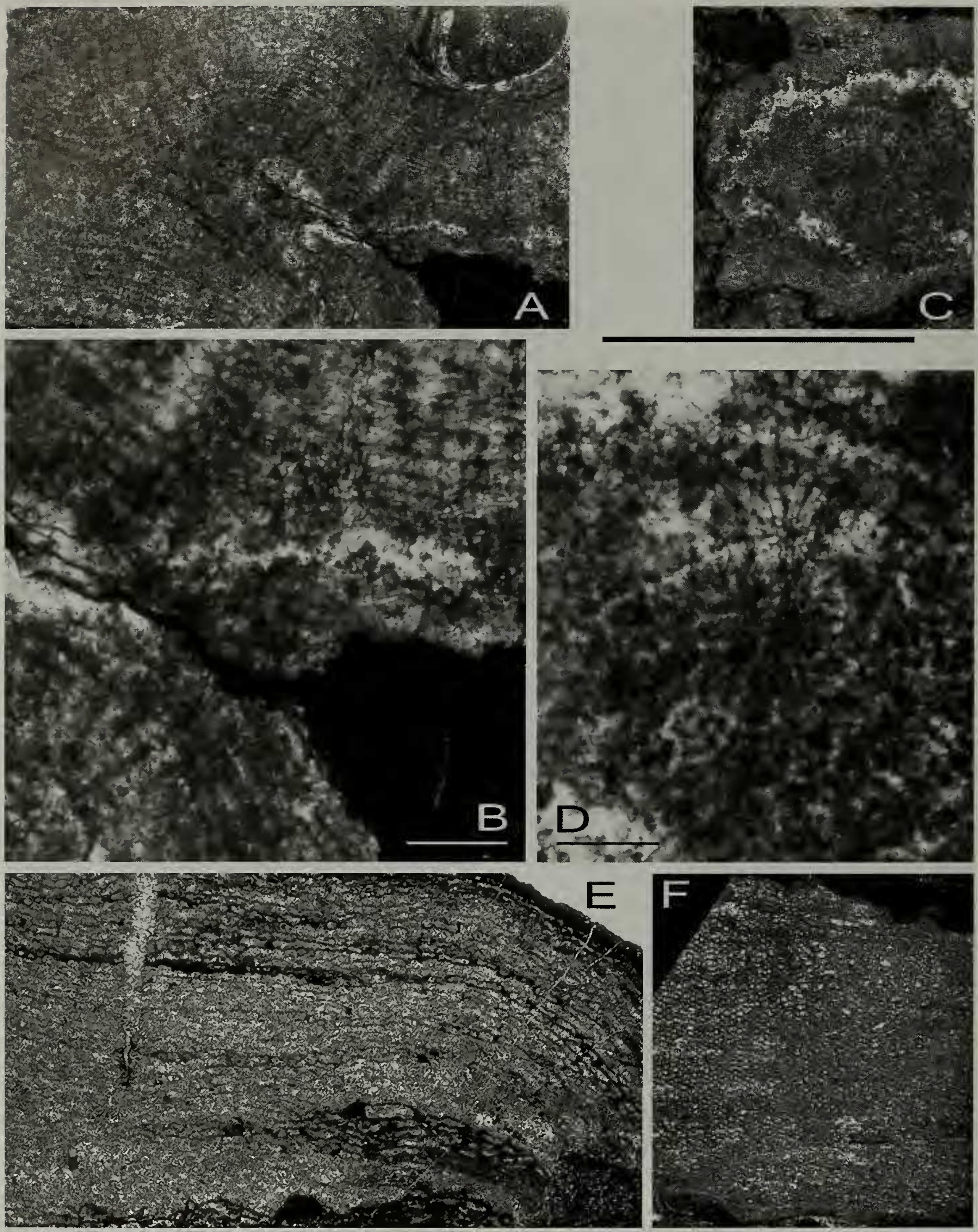


Figure 9. Stromatoporoids from Eastonian limestone, Marsden prospect at Barmedman Creek. Scale bar beneath (C) represents 10 mm and applies to (A), (C), (E) and (F); scale bars in photos (B) and (D) represent 1 mm. A-D, *Stratodictyon ozakii* Webby, 1969, from 182 m in ACDMN 043; longitudinal (A) and transverse (C) sections, with respective enlargements (B) and (D); note columns spanning up to seven laminae in lower left corner of (B), and astrorhizal canal in upper centre of (D). E, *Clathrodictyon* cf. *microundulatum* Nestor, 1964, from 229 m in ACDMN 043. F, *Ecclimadictyon* sp., longitudinal section, from 229 m in ACDMN 043.

Table 2. Distribution of coral and sponge species in Newcrest boreholes, Marsden prospect, Barmedman Creek.

Borehole	Depth (m)	Assemblage
DDMN 042	399	*Tetradium tenue* Webby & Semeniuk, 1971
	405	*Tetradium tenue* Webby & Semeniuk, 1971
	406	*Tetradium tenue* Webby & Semeniuk, 1971; *Tetradium* sp.
ACDMN 043	173	*Halysites* sp.
	174	*Paleofavosites*? sp.
	179-180	*Cystihalysites* sp.
	181	*Cliefdenella* cf. *perdentata* Webby & Morris, 1976
	182	*Stratodictyon ozakii* Webby, 1969; *Cliefdenella* sp.
	192	*Labechiella variabilis* (Yabe & Sugiyama, 1930)
	229	*Bajgolia* cf. *grandis* Webby, 1977; *Palaeophyllum* sp.; *Propora bowanensis* Hill, 1957; heliolitid indet.; *Clathrodictyon* cf. *microundulatum* Nestor, 1964; *Ecclimadictyon* sp.
	232	*Bajgolia*? cf. *grandis* Webby, 1977
ACDMN 045	275	indeterminate
	276	*Tetradium*? sp.

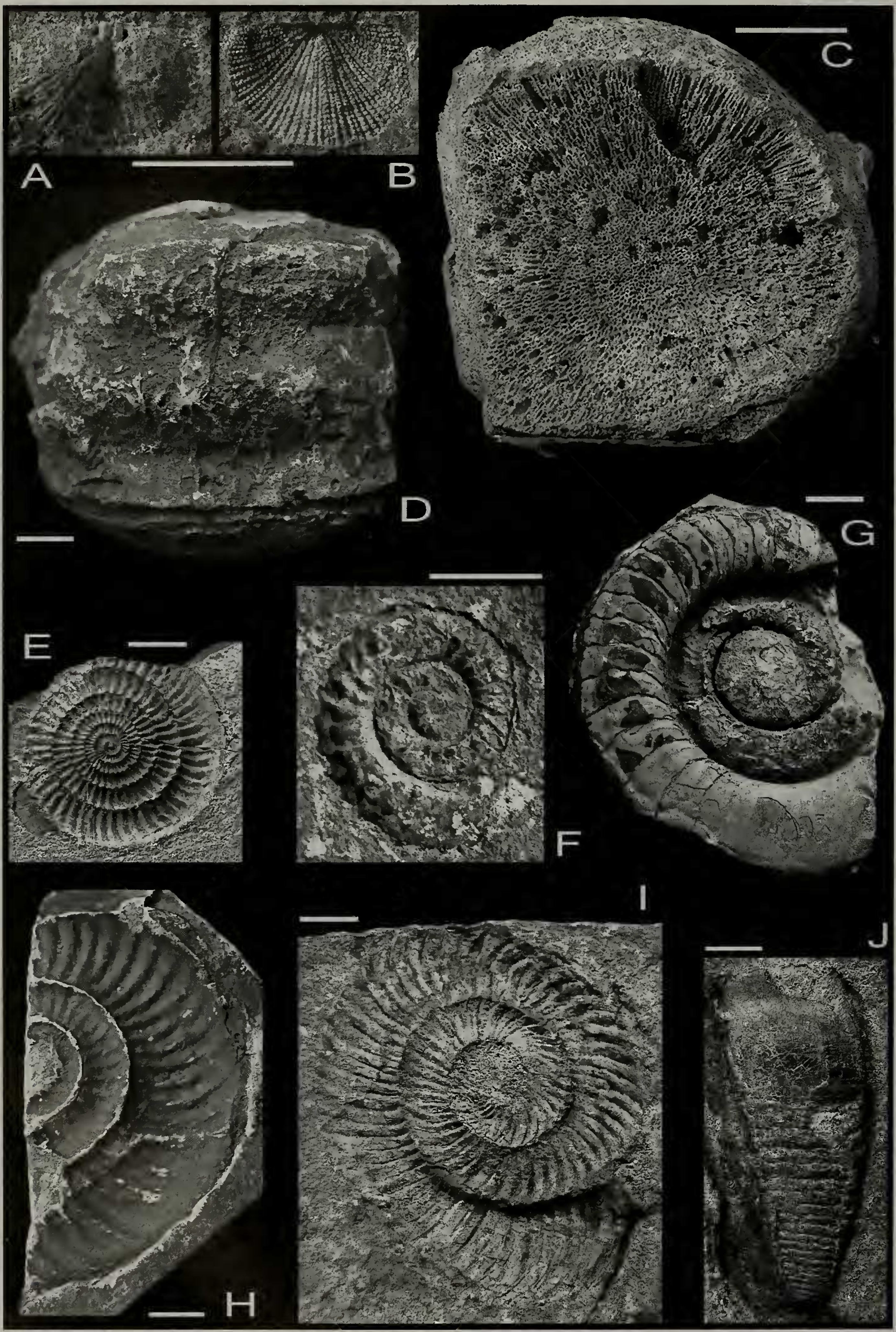
the quarry occurs in stratigraphically higher beds, composed of coarser silts to fine sands that are partly silicified. These strata are distinguished by the high concentration of siliceous sponges (predominantly the spheroidal *Hindia*) which are clustered on the surface of beds. Thin maroon-coloured medium to coarse grained sandstone layers are rarely interspersed in the siltstone succession towards the basal beds exposed in the working quarry. Most beds at this locality dip towards the east at variable angles, from nearly zero to about 30 degrees. Only an estimated 20-30 metres of continuous section is exposed in the floor of the working quarry; the true thickness of the formation is considerably in excess of this, but is unmeasurable due to structural complexity. Siltstone beds on the western side of this quarry are erratic in trend, but generally dip towards the southwest at low angles. In the wall and floor of the disused quarry to the south, folding and associated faulting is particularly prominent.

Fossils from the Gibber Trig outcrop, identified by K. Sherrard, were first referred to by Wynn (1961), with this information republished by Moye et al. (in Packham 1969, p. 98). Subsequent unpublished reports on the faunal assemblage from these outcrops were provided by Sherwin (1982, 1985), Pickett (1986) and Percival (1999). Faunal lists from the earlier of these reports were subsequently published in the palaeontological appendix to the Cootamundra 1:250 000 Geological Sheet Explanatory Notes (Warren et al. 1995). Percival's (1999) identifications were incorporated into the Forbes 1:250 000 Geological Sheet Explanatory Notes (Lyons et al. 2000). With the exception of a nautiloid depicted by Percival and Lyons (2000) (here re-illustrated in Figure 10E), none of the fauna has previously been illustrated or described.

The graptolite assemblage indicates species that range in age from middle Eastonian to middle Bolindian; they include *Dicellograptus gravis* Keble and Harris, *Dicellograptus ornatus* (Elles and Wood), *Normalograptus angustus* (Perner), *Orthograptus* ex. gr. *amplexicaulis* (J. Hall), together with *Ptilograptus* sp., and an unidentified climacograptid. Overlap of the published ranges (VandenBerg and Cooper 1992) suggests an early Bolindian (Bo 2) age is most probable for the formation. Coiled tarphyceratid nautiloids, referred to *Discoceras*? sp. and a large indeterminate genus, are the most spectacular component of the shelly fauna (Fig. 10), but cannot be precisely identified due to their preservation mainly as external moulds. Other faunal elements include indeterminate cyrtoconic brevicone and orthoconic nautiloids, a small dalmanelloid? and large multicostate orthide? brachiopods, and the siliceous sponges previously mentioned.

Palaeoecological interpretation

The association in the Jingerangle Formation of graptolites, nautiloids of nektic habit (particularly the proliferation of tarphyceratids, which are thought to have been strong swimmers), and lithistid sponges is interpreted to indicate deep water environments at depths typical of Benthic Assemblage 4-5 (perhaps 50-200 m). A somewhat comparable faunal association is present in the basal Malongulli Formation in the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Cliefden Caves area between Orange and Cowra (Webby 1992, Percival and Webby 1996). Here, a diverse suite of sponges (including *Hindia*) populated the periplatformal zone, between the shelf edge and the deep basin (Rigby and Webby 1988). The Malongulli sponge assemblage was subsequently dislodged as debris flows or slumps into the lower slope and basinal sediments (equivalent to Benthic Assemblage 6), which are largely comprised of spiculitic siltstones with a faunal association of graptolites, trilobites, and diminutive lingulate and plectambonitoid brachiopods. In the case of the Jingerangle Formation, the *Hindia*-dominated fauna is preserved in laminated sediments that are not slumped and are interpreted to have formed *in situ*. Fauna in the Bolindian section of the Cotton Formation consists only of graptolites, orthoconic nautiloids, ostracodes (Sherwin 1973) and the lingulate brachiopod *Paterula* (Percival 1978); presumably these sediments were deposited at depths slightly greater than that interpreted for the Jingerangle Formation.

REGIONAL CORRELATION

Volcanic and intrusive host rocks of the Marsden copper-gold prospect belong to the Cowal volcanic complex, the geology of which is known only from exploratory drilling (Miles and Brooker 1998, Downes and Burton 1999). Beneath Lake Cowal this complex consists of calc-alkaline to shoshonitic volcanics and associated sedimentary rocks, including volcaniclastics, mass-flow deposits, and laminated mudstones and siltstones of deeper water origin. This succession is apparently older than early Darriwilian age, as it is intruded by diorites and granodiorites, including one dated ($^{40}Ar/^{39}Ar$) at 465.7 ± 1 Ma (Miles and Brooker 1998). Rocks of the Cowal volcanic complex could therefore have formed the basement on which the Eastonian limestones (not recognised despite extensive exploratory drilling at Lake Cowal) accumulated in shallow water environments. Stratigraphic relationships in the cored holes from the Marsden prospect are not clear due to structural complications. Newcrest DDMN 042 intersected approximately 245 m of monzodiorite above the Eastonian limestone, with evidence from the core log that these units are fault-juxtaposed. Beneath 120 m of regolith (an average thickness for this area), ACDMN 043 passed through 20 m of volcaniclastic sandstone and siltstone (undated) before intersecting limestone that continued to the bottom of the hole.

In an adjacent tectonic block separated from the Lake Cowal-Marsden region by a major thrust fault (Fig. 1), the Jingerangle Formation is also associated with igneous rocks, known as the Currumburrama volcanics. Here, however, relationships are even more obscured by the fact that this buried igneous complex has thus far only been recognised on the basis of its distinctive geophysical response. Age and composition of the Currumburrama volcanics is unknown, and their stratigraphic position relative to the Jingerangle Formation is uncertain.

Thus the only significant information to assist regional correlation with other areas of the Macquarie Arc derives from the fossiliferous rocks documented in this study. The Eastonian limestones from the Marsden prospect contain some macrofossils and conodonts that have not previously been recognised in the Junee-Narromine Volcanic Belt. For example, the coral *Tetradium tenue*, prominent in DDMN 042, is elsewhere known only from the Daylesford Limestone of the Bowan Park Group on the western flank of the Molong Volcanic Belt. Such differences are probably environmentally controlled. Overall, the Barmedman Creek limestones most closely correspond to the succession in the vicinity of Gunningbland (west of Parkes), through the upper part of the Billabong Creek Limestone (Ea1-2) and into the overlying Gunningbland Formation which includes intermittent limestones of Ea3 age (Pickett and Percival 2001). The Gunningbland area lies 90 km to the northeast of the Marsden prospect, along the trend of the Junee-Narromine Volcanic Belt (Fig.

Figure 10 LEFT. Fossils from the Jingerangle Formation. Scale bars represent 10 mm. A-B, indeterminate dalmanelloid brachiopod. A, dorsal valve internal mould, and B, external mould of same individual MMF36611a-b, from roadbase quarry, immediately south of Jingerangle State Forest. C, natural cross section of *Hindia sphaeroidalis* Duncan, 1879, MMF36600, from roadbase quarry, immediately south of Jingerangle State Forest. D-J, nautiloids from Jingerangle Formation collected from scree on hill behind "Bland Farm" homestead; original specimens in possession of landholder. D, weathered profile of large indeterminate orthocone. E, *Discoceras*? sp., latex impression from external mould. F, latex impression from external mould of micromorphic or juvenile individual of indeterminate tarphyceratid. G-I, large indeterminate tarphyceratid; G, latex replica of internal mould showing septa and living chamber. H, latex impression from partial external mould. I, latex impression from external mould. J, latex impression from external mould of indeterminate cyrtoconic brevicone, living chamber uppermost.

1). Also on this trend to the west of Forbes, about 75 km northeast of the Marsden prospect, are outcrops of the lower (Bolindian age) Cotton Formation which — as previously observed — is the closest analogue to the Jingerangle Formation in terms of lithology, depositional environment and age. It would be reasonable, given the relatively well-documented Late Ordovician succession in the Forbes-Parkes region, to interpret the Jingerangle Formation as a similarly widespread deep water unit overlying the older limestone and volcanic rocks encountered in the Barmedman Creek area. However, as these units are presently separated by a major thrust fault, this relationship remains conjectural.

TAXONOMIC NOTES

Responsibility for palaeontological discussion is indicated for each phylum. Some taxa have been documented by illustration only where material is insufficient for comment or where species are well known. Specimens are catalogued in the Palaeontological Collection of the Geological Survey of NSW (prefix MMF for macrofossils, MMMC for conodonts), housed in the Londonderry Geoscience Centre in western Sydney.

Conodonts [Zhen]

Only grandiform and compressiform elements of *B. compressa* were recovered from the Barmedman Creek samples (Fig. 3A-D). Both illustrated specimens of compressiform elements show a straight section of anterior margin near the antero-basal corner, recognised as the most distinctive character to differentiate *B. compressa* from the stratigraphically slightly younger *B. confluens* (Zhen et al. 2004).

Two specimens are doubtfully referred to *Plectodina tenuis*. One, identified as the Pb element (Fig. 3L), bears anterior and posterior processes more or less equal in length, but has a shorter posterior process in comparison with elements reported from the Cliefden Caves Limestone Group (Zhen and Webby 1995). A Pb element of *P. tenuis* with a similarly short posterior process was also reported from the Late Ordovician Vauréal Formation of Anticosti Island, Quebec (Nowlan and Barnes 1981, pl. 4, fig. 20).

Rhipidognathus sp. (Fig. 4F-I) with only Pa, Pb, and Sb elements recovered may represent a new species. Both Pa and Pb elements are angulate with denticulate anterior and posterior processes, but the Pb element bears a large robust cusp (Fig. 4I), whereas the cusp in the Pa element is indistinguishable from adjacent denticles (Fig. 4G, H). The Sb element is palmate digyrate, slightly asymmetrical with a prominent basal tongue on the anterior face that extends below basal margin (Fig. 4F).

Corals [Pickett]

The halysitids represent the most unusual elements of the coral fauna from the Barmedman Creek limestone. The form determined as *Halysites* sp. (Fig. 5A, B) is definitely not the same as the only other true *Halysites* known from the Ordovician, *H. praecedens* Webby and Semeniuk 1969; that species has subrounded corallites 1.2 – 2.0 mm long, with tabulae at 6 – 7 in 5 mm, whereas in the present material the corallites are elongate and the palisades only slightly wider at their widest point, and the tabulae are much more frequent: up to 8 in 2 mm. The *Cystihalysites* has clearly developed cystose coenenchymal tubules (Fig. 5C-E), but the material is too scant for proper description.

The poorly preserved specimen designated *Tetradium*? sp. (Fig. 6C), from 406 m depth in borehole DDMN 042 at Barmedman Creek, is cerioid or subcerioid in habit, with complete, distant tabulae, a double-layered wall, and apparently without either mural pores or septa. The absence of mural pores and presence of a double-layered wall suggest an early stauriid rugosan such as *Favistina* or *Crenulites*, but both of these have septa, and the tabulae of *Crenulites* are distinctively shaped. *Foerstephyllum* is also ruled out by the absence of septa. *Tetradium*? sp. may be related to a form referred to *Tetradium* sp. A by Webby and Semeniuk (1971, pl. 17, figs 4, 5), that has inconspicuous septa, angular corallites, and thin walls. Cerioid or sub-cerioid corals known from near this level in NSW include a variety of auloporoid forms described by Webby (1977). However, none of these appears to show the thin walls of the present specimens.

The material of *Propora bowanensis* Hill, 1957 (Fig. 7C-E) falls within the variation reported for this species by Webby and Kruse (1984), though rather more consistently with the *Heliolites* end of the spectrum.

Sponges [Pickett]

The Geological Survey of NSW collections include a large number (MMF 29519-29538, 36592-36608) of well preserved individuals of *Hindia sphaeroidalis* Duncan, 1879 from the Jingerangle Formation (Pickett 1986). The largest of these is illustrated (Fig. 10C). This species was also reported by Rigby and Webby (1988) from three of their four horizons in the Malongulli Formation near Cliefden Caves, and additionally from Late Ordovician strata at "Currajong Park", Gunningbland, west of Parkes.

The stromatoporoid identified as *Labechiella variabilis* (Yabe and Sugiyama, 1930) (Fig. 8C, D) has pillars up to 0.6 mm in diameter, somewhat stouter than those reported for this species by Webby (1969). *Stratodictyon* cf *ozakii* Webby, 1969 from 182 m in ACDMN 043 shows well-developed pillars, stouter than the laminae, which may cross up to seven laminae (Fig. 9B). The transverse section (Fig. 9C, D) shows a distinct astrorhizal canal. Stromatoporoids from the 229 m level in this drill hole include *Ecclimadictyon* sp. (Fig. 9F) and *Clathrodictyon* cf *microundulatum* Nestor, 1964. The latter, represented by a single longitudinal section (Fig. 9E), accords well with the specimen figured by Webby (1969, pl. 127, fig. 3). As noted by Webby, his specimens of *C.* cf. *microundulatum* are associated with, and in some cases resemble, *Ecclimadictyon*. Co-occurrence of these forms in the Marsden prospect core is reminiscent of this situation.

Brachiopods [Percival]

Brachiopods are uncommon in the Jingerangle Formation. Most specimens are poorly preserved external impressions of weakly biconvex multicostate valves with wide hingelines, probably referable to an indeterminate orthide?

The only example presently known from the Jingerangle Formation of a small dalmanelloid?, represented by a dorsal valve, is illustrated (Fig. 10A-B) as it is better preserved than the other brachiopods. The valve is transversely quadrate in outline, of low convexity with a narrow median sulcus; the distinctive ornament is interpreted from the exterior mould as comprising closely spaced coarse exopunctae regularly distributed between the fine multicostellae. Internally, the cardinalia consist of a simple blade-like cardinal process, with rod-shaped brachiophores apparently supported by delicate fulcral plates. A median septum is not developed, although the narrow median sulcus is ventrally directed to mimic a raised ridge. Without details of the ventral valve it is impossible to assign this specimen at family level, but general affinities with the paurorthids are suggested. No comparable shells have been noted elsewhere in the Late Ordovician brachiopod faunas from central-western N.S.W.

Nautiloids [Percival]

All nautiloids from the Jingerangle Formation, with the exception of a section of a large indeterminate orthocone (Fig. 10D), are preserved as external moulds or an internal mould impression. The position of the siphuncle, and shape of the septa crossing the dorsal whorl profile, are unable to be determined, making generic identification uncertain if not impossible. Nevertheless, two genera of coiled nautiloids can be readily distinguished. A tightly coiled form is referred to *Discoceras*? (Fig. 10E), although *Trocholites*? or *Hardmanoceras*? may be equally valid identifications. Several large slowly expanding conchs (Fig. 10G-I) with coarse ribbing appear to be broadly externally similar to an indeterminate tarphyceratid illustrated from the Gunningbland Shale Member (Ea 3 age) of the Goonumbla Volcanics at Gunningbland, west of Parkes (Stait et al. 1985). A small individual (Fig. 10F) may represent a juvenile or micromorphic form of this tarphyceratid.

ACKNOWLEDGMENTS

We are grateful to the owners of "Bland Farm" who permitted us access to study the fossils in the Jingerangle Formation, and to Irvine Hay of Newcrest Exploration who alerted us to the presence of limestone in core from their Barmedman Creek prospect in the Marsden area. Gary Dargan (NSW Geological Survey) processed the conodont samples and prepared thin sections of fossils in the limestone. Photography of macrofossils was undertaken by David Barnes (NSW Department of Primary Industries) and the figures were drafted by Cheryl Hormann (NSW Geological Survey). Scanning electron microscope illustrations of the conodonts were prepared in the Electron Microscope Unit of the Australian Museum. Reviews by two anonymous referees assisted us in polishing the manuscript. This paper is a contribution to IGCP Project No. 503: Ordovician Palaeogeography and Palaeoclimate. Ian Percival and John Pickett publish with the permission of the Deputy Director-General, NSW Department of Primary Industries - Mineral Resources Division.

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APPENDIX
locality data and faunal lists

Grid Reference 560500mE 6244240mN, Marsden (8430 II and III) 1:50 000 sheet
Jingerangle Formation in roadbase quarry, immediately south of Jingerangle State Forest.

Brachiopod:	dorsal valve of small dalmanelloid?
Sponge:	*Hindia sphaeroidalis* Duncan, 1879
	indeterminate small conical form
	gigantic monaxons (several cms in length)
echinoderm:	crinoid ossicle
graptolite:	indeterminate climacograptid?
	Ptilograptus sp

Grid Reference 560500mE 6243280mN, Marsden (8430 II and III) 1:50 000 sheet
Jingerangle Formation in disused quarry, just west of "Bland Farm" homestead.

Graptolites:	indeterminate small climacograptid
	Dicellograptus gravis Keble and Harris
	Dicellograptus ornatus (Elles and Wood)
	Normalograptus angustus (Perner)
	Orthograptus ex. gr. *amplexicaulis* (J. Hall)

(centred on) **Grid Reference 560500mE 6243100mN, Marsden 1:50 000 sheet**
Jingerangle Formation, scree on hillside behind "Bland Farm" homestead.

Brachiopod:	indeterminate large multicostate orthide?
Nautiloids:	*Discoceras*? sp
	indeterminate tarphyceratid
	indeterminate cyrtoconic brevicone
	indeterminate orthocone

core from Newcrest drill hole DDMN 042, Marsden prospect (tenement EL5524)
commenced 14/3/2002, completed 27/3/2002, TD 460.7 m
GR 541658 mE 6256524 mN (GDA co-ordinates)
for further details of micro- and macrofauna, refer to Tables 1 and 2

Depth	387 m	microfossil sample	C2090	barren
	389 m		C2091	barren
	391.2 m		C2092	barren
	391.2-395.6 m		C2071	conodonts
	397 m		C2093	conodonts and ostracode
	399 m		C2094	conodonts, macrofossil: coral (*Tetradium*)
	401 m		C2095	conodonts
	403.9 m		C2096	conodonts
	403.9-408 m		C2072	conodonts, ostracodes, scolecodonts
	405 m		macrofossil sample: coral (*Tetradium*)	
	406 m		macrofossil sample: coral (*Tetradium*)	
	410 m		C2097	conodont
	412 m		C2098	ostracode and bryozoa
	414 m		C2099	bryozoa and lingulate brachiopod fragment
	416 m		C2100	conodonts
	418.3 m		C2101	barren

core from Newcrest drill hole ACDMN 043, Marsden prospect (tenement EL5524)
commenced 2/4/2002, completed 7/4/2002, TD 238.7 m
GR 542347 mE 6255784 mN (GDA co-ordinates)
for further details of micro- and macrofauna, refer to Tables 1 and 2

Depth	141 m	microfossil sample	C2102 benthic forams, ostracodes
	143 m		C2103 barren
	170.7-175 m		C2073 conodonts
	173 m		macrofossil sample: coral (*Halysites*)
	174 m		macrofossil sample: coral (*Paleofavosites*?)
	179.5-183.9 m		C2074 conodonts, silicified corals
	179-180 m		macrofossil sample: coral (*Cystihalysites*)
	181 m		macrofossil sample: sponge (*Cliefdenella*)
	182 m		sponge (*Cliefdenella*), stromatoporoid (*Stratodictyon*)
	189-192.8 m		C2075 conodonts
	192 m		macrofossil sample: stromatoporoid (*Labechiella*)
	212 m		C2104 barren
	214 m		C2105 barren
	216 m		C2106 barren
	227.8-232 m		C2076 fragment of indet. conodont
	229 m		diverse corals, stromatoporoids *Ecclimadictyon*, *Clathrodictyon*
	232 m		macrofossil sample: coral (*Bajgolia*?)